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Short-term memory for auditory digit sequences as a function of systematic manipulation of encoding technique, digit duration, and interdigit interval

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SHORT-TERM MEMORY FOR AUDITORY DIGIT
SEQUENCES AS A FUNCTION OF SYSTEMATIC MANIPULATION
OF ENCODING TECHNIQUE, DIGIT DURATION, AND INTERDIGIT INTERVAL

A Thesis
Presented to the
Department of Psychology
and the
Faculty of the Graduate College
University of Nebraska at Omaha

In Partial Fulfillment
of the Requirements for the Degree
Master of Arts

by
John G. Miscik
May, 1972

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University of Nebraska at Omaha, in partial fulfillment of the
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Abstract

The experiment tested whether short term retention for auditory digit sequences could be improved by efficient encoding techniques (ET) and increases in either digit duration (DD) or interdigit interval (IDI). All three hypotheses received strong support from the data. In addition, analysis of interactions between length of retention interval (RI) and DD, IDI, and ET led to the conclusions that longer DD and IDI permit increased resistance to forgetting during RI, while efficient ET improves retention regardless of RI.

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In short-term memory (STM) experiments, errors in recall have traditionally served as a measure of retention loss. The question arises as to whether errors in recall are due to forgetting, or to inadequate encoding, or both. It has been shown that accuracy of recall varies indirectly with the rate of stimulus presentation (e.g., Aaronson, 1968). It is possible that stimulus presentation rate could have this effect by determining the amount of time available for encoding. A fast presentation rate, for example, might not allow enough time for Ss to employ an efficient encoding technique (ET). This lack of time could manifest itself as errors in recall. Certainly, a better understanding of the factors influencing the encoding process could facilitate understanding of retention.

The STM trace is characterized as being subject to rapid decay in contrast to the stability and permanence of long-term memory traces (Marx, 1969, Ch. 19). The autonomous decay of the STM trace is believed to be a function of time and has been demonstrated as occurring during very short intervals after the presentation of verbal items. Peterson and Peterson (1959) found a decrement in retention across six short retention intervals while controlling for the effects of rehearsal. The decrement in retention found by the Petersons supports the decay theory; however, it does not confirm time as the sole factor responsible for this phenomenon.

Another factor affecting retention loss is interference. Waugh and Norman (1965) and Norman (1966) conducted studies in which they presented a list of 15 digits followed by a probe digit that had appeared earlier in the list. Ss were to recall

the digit that had followed the probe digit in the list. The rate of presentation was varied. Both studies found rate of decay to be a function of the number of intervening items (interference) irrespective of rate of presentation. However, there were some trends in their data that suggest that temporal delay may also be important. Wickelgren (1970), using a probe recognition paradigm, presented a list of 9 or 15 letters at a rate of one, two, or four letters per second followed by a test letter, followed by the S's decision as to whether the test letter appeared in the previous list. Wickelgren found that both time and the number of intervening items are important factors in producing decay in STM.

There are two interesting possibilities with respect to the effects on memory of time and interference. By keeping interference constant and by varying the stimulus presentation rate it was thought that, first, reducing the rate might allow more time for decay, and therefore result in lower recall accuracy (this would support the trace decay hypothesis), and second, reducing the rate might allow more time for organization of the stimulus and therefore result in higher recall accuracy.

Experimental results provide evidence for both of these possibilities. Pollack, Johnson, and Knaff (1959) and Pollack and Johnson (1963) showed greater recall accuracy at slower rates using running memory span paradigms with rates ranging from .125 to four items per sec. In another study Pollack (1952) found that both the percentage of items recalled correctly and the amount of information transmitted increased as the presentation rate of auditory sequences

of digits and letters was decreased from four to .25 items per sec. Pollack suggested that SS performed better at the slow rates because they could use the extra time for encoding and organizing the stimulus information. Limiting the amount of time available between the items by increasing the rate would restrict the range of encoding strategies that SS could employ, perhaps preventing them from using an optimal strategy.

Two other experimenters finding better performance at slow rather than fast presentation rates in STM tasks were Sitterley (1968), studying order recall of visually presented digits, and Smith (1971), studying order recall of auditory digits.

A few studies have shown an increase in recall accuracy as the rate of stimulus presentation was increased. Conrad and Hille (1958) presented auditory sequences at 30 or 90 digits per minute. In support of their memory-trace-decay hypothesis, more errors were found with the slower rate of presentation. Posner (1964), attempting to show that increasing the rate of presentation will improve recall because of decreased time in storage in tasks which tend to reduce the use of recall strategies, presented eight-digit auditory sequences at either 30 or 90 digits per minute. He found higher accuracy for the fast than for the slow rate for order recall in agreement with Conrad and Hille's data.

The precise factors which cause a slow rate of presentation to facilitate retention over a fast rate in some experiments, but to have the opposite effect in others have not yet been identified. It is possible that variations in certain perceptual factors among

the various studies can in part account for the conflicting results. In most previous studies, stimulus intensity, stimulus intelligibility, stimulus duration, and other factors that may effect perception were not carefully controlled or measured (Aaronson, 1967). Pollack and Rubenstein's (1963) data suggest that decreasing the intelligibility and thereby increasing the time needed to perceive the stimuli may have some effects similar to those of increasing the rate. Aaronson (1967) suggested that stimulus intelligibility is important in determining the effects of rate on recall.

One way of increasing presentation rate has been to uniformly delete small sections from tape recordings of natural speech and compress the remainder. Garvey (1958) used this speech compression method and found that speech accelerated as much as two times the original speed still provided 95% or greater intelligibility. Not until acceleration reached four times original speed did intelligibility drop below 50%.

Essentially, the presentation rate in STM experiments can be increased either by decreasing the stimulus duration, by decreasing the interstimulus interval, or a combination of both. Most studies in STM have failed to systematically manipulate these two variables. Consequently, the results may well be confounded. One study conducted by Herrington and reported by Bergström (1907) manipulated interstimulus interval and stimulus duration independently. Bergström reported that varying stimulus duration had no effect on retention, while longer interstimulus intervals were associated with higher recall. There have been two studies that manipulated stim-

ulus duration and interstimulus interval using digit strings as the stimuli. Thus, the amount of time it took to present one digit of the string was termed digit duration (DD), and the amount of time between each digit was termed interdigit interval (IDI). Sitterley (1968) systematically varied DD and IDI for visually presented digits and found that retention increased when either of these variables was increased. Smith (1971) also found that retention increased with an increase in either DD or IDI for auditory presentations of four-digit strings.

The increase in retention when DD is constant and IDI is increased has been attributed to the fact that more time is available to Ss for organization and rehearsal of material (Posner, 1963). The increase in retention with an increase in DD, when IDI is held constant, is not readily explained. Sitterley (1968) assumed that whatever the process was that caused the increase in retention, it must have been operating while new stimulus information was being received by S. Thus, Ss were seen as receiving new information and simultaneously processing, categorizing, and storing old information.

Evidence against Sitterley's assumption was provided by Wickelgren (1970) who found that the decay rate for previous items appeared to be greater during the time for acquisition of a new item than during the time between acquisition of adjacent items. At present the increase in retention with an increase in DD while IDI is held constant has not been adequately explained. However, a possible explanation might be that any DD over that which is needed to make the digit

intelligible to the S can be used for organizational time or rehearsal.

In general stimulus organization techniques have been found to facilitate retention. For example, Morganstein (1970) studied the effects on recall of ET and found that: efficient encoding facilitates recall; organizational processes structure the stimuli in storage; S's placement strategy in storage is a result of a choice from among his pre-existing organizational techniques. Chunking is an encoding and an organizational process. The chunking hypothesis contends that individuals remember not only separate items of information, but also "chunks" of information. Remembering information as chunks permits an increase in the immediate memory span (Miller, 1956). Melton (1963) has contended that the rate of forgetting of a unit presented once is dependent upon the amount of intraunit interference and that this interference is a function of the number of chunks encoded within the total stimulus as distinct from the total number of physical elements (letters, numbers, phrases) present. Melton's contention is supported by Murdock's (1961) findings that one-word stimuli are remembered significantly better than three-word stimuli due to three-word stimuli having greater intraunit interference.

A basic assumption is that chunking, being an organizational process, requires time. If it can be shown that chunking facilitates retention, then it could be proposed that the amount of DD over that which is needed for intelligibility could be used for organizational techniques or for other processes such as rehearsal.

The present study was designed to systematically manipulate ET, DD, IDI, trial blocks (TB), and retention interval (RI). When the stimuli are encoded into chunks, it is believed that the Ss who are encoding three-digit chunks will perform significantly better than Ss who are encoding two-digit chunks, who in turn will do significantly better than Ss that do not chunk. It is believed that the proportion of correct responses will significantly increase when either, or both, DD and IDI are increased. As in Smith's (1971) study, it is believed that DD and IDI will interact with RI, with greater retention differences shown at the longer RIs. It is believed that the proportion of correct responses will significantly decrease as the retention interval is increased. As in Smith's (1971) study, there should be no TB effect.

Method

Subjects and Design

The sample used in this study consisted of 90 Ss drawn from the introductory psychology course at the University of Nebraska at Omaha. The Ss were volunteers who participated for extra credit. Five Ss were randomly assigned to each of the 18 between Ss cells of a 2 (DD) X 3 (IDI) X 3 (ET) X 5 (TB) X 5 (RI) factorial design with repeated measures on the last two factors.

The items for verbal recall were six-digit number sequences. Each digit was randomly selected. Only arabic numerals from one to nine were used as digits and no digit appeared twice in the same number. Presentation of a six-digit number constituted one trial with a total of 50 trials. There were six presentation rate

conditions and three ET (chunking) conditions as shown in Table I. All conditions employed the same randomized digit sequences. Levels of DD were .5 sec. and 1 sec., while levels of IDI were 0 sec., .5 sec., and 1 sec.

Table I

Stimulus Presentation Rate and Stimulus ET Conditions

<u>Presentation Rate</u>			<u>ET Conditions</u>
<u>Cond.</u>	<u>DD</u>	<u>IDI</u>	
I (TC)	.5"	0"	No Chunking: (1-8-6-3-7-2)
II	1.0"	0"	Chunking by twos: (18-63-72)
III (TC)	.5"	.5"	Chunking by threes: (186-372)
IV	1.0"	.5"	Note: Each of the ET conditions was employed at each of the six presentation rate conditions.
V (TC)	.5"	1.0"	
VI	1.0"	1.0"	
			(TC) Time compressed

Five RIs were used: 0, 2, 4, 8, and 16 sec. For purposes of randomization the trials were divided into 10 blocks of five trials each. Within each block the S was tested once for each RI. The order in which each RI occurred was determined from a random number table and remained constant for all Ss. The TBs were derived by dividing the 50 trials into five blocks of 10 trials each. Therefore, within each TB the S was tested twice for each RI.

Apparatus and Materials

All digits were tape recorded at 3.75 in/sec. tape speed using

a standard two-track monaural tape recorder equipped with a remote start-stop switch. The three time compressed tapes were obtained by processing the recorded digits through a Whirling Dervish speech-time compressor (model SL 14) manufactured by Discerned Sound. The Dervish is an electromechanical device that can discard portions of recorded material. For this study portions of 38 msec. were alternately discarded with the remaining portions being compressed by a factor of two. The IDI for the time compressed tapes was processed in the same manner and simultaneously with DD. As an example, the .5 sec. DD/.5 sec. IDI condition was produced by time compressing a 1 sec. DD/1 sec. IDI tape.

To prevent rehearsal during RI, Ss were required to read aloud from a chart containing 12 rows of 10 one-inch high letters. Each letter was randomly selected from the alphabet, excluding the letters I and O which were not used. It was felt that continuous verbal activity during the time between presentation and signal to recall would minimize rehearsal behavior (Peterson and Peterson, 1959). A chart, using .5 in. numbers, was employed to give Ss a pictorial example of how to group the digits for the three ET conditions (i.e., 1-8-6-3-7-2; 18-63-72; 186-372). The same digits were used for all three examples. Timing was accomplished using a standard .10 sec. stop watch.

Procedure

S and E were seated at a table in a 10 X 12 ft. semi-sound-proof cubicle. The tape recorder was positioned on the table between S and E. The scrambled alphabet chart was taped to the wall at eye

level approximately three ft. in front of S. The EI conditions were established by instructions. As an example, Ss assigned to chunk by threes were instructed to group the digits by threes and to refrain from using any other technique. For complete instructions given to Ss see the Appendix. The Ss received their instructions from a recorded tape at a normal conversation rate. As each S listened to the instructions, he was shown the pictorial example of how to group the digits.

On each trial S heard a six-digit number on the tape recorder and then immediately began reading the scrambled alphabet chart as rapidly as he could until asked to recall the number by E.

All Ss were given six practice trials prior to starting the experiment. These were also on tape.

Results

Only those digits that were accurately recalled in their proper serial position were scored as being correct. Since each RI was tested twice within each trial block, the maximum number correct for each retention interval would be 12 (six-digit numbers X two tests). The score entered into the previously described analysis of variance was the proportion correct of 12. All contrasts were accomplished using the Tukey A procedure for multiple comparisons.

Ss averaged a proportion of .47 correct responses at the .5 sec. DD and .52 at the 1 sec. DD. The difference between these two levels was significant $F(1,72) = 9.82, p < .005$.

As IDI was increased from 0 sec. to .5 sec. to 1 sec., retention increased. At 0 sec. IDI Ss averaged .47, at the .5 sec. IDI .48,

and .54 at the 1 sec. IDI. These differences were found to be significant $F(2,72) = 5.26, p < .01$. All contrasts were significant at the .01 level.

The effect of BT yielded an $F(2,72) = 21.34, p < .001$. Ss averaged .41 in the no chunking condition, .55 when chunking by twos, and .53 when chunking by threes. All contrasts were significant at the .01 level.

The average proportion of correct responses for the 0, 2, 4, 8, and 16 sec. retention intervals were .82, .54, .45, .37, and .30, respectively. The analysis resulted in an $F(4,288) = 426.47, p < .001$.

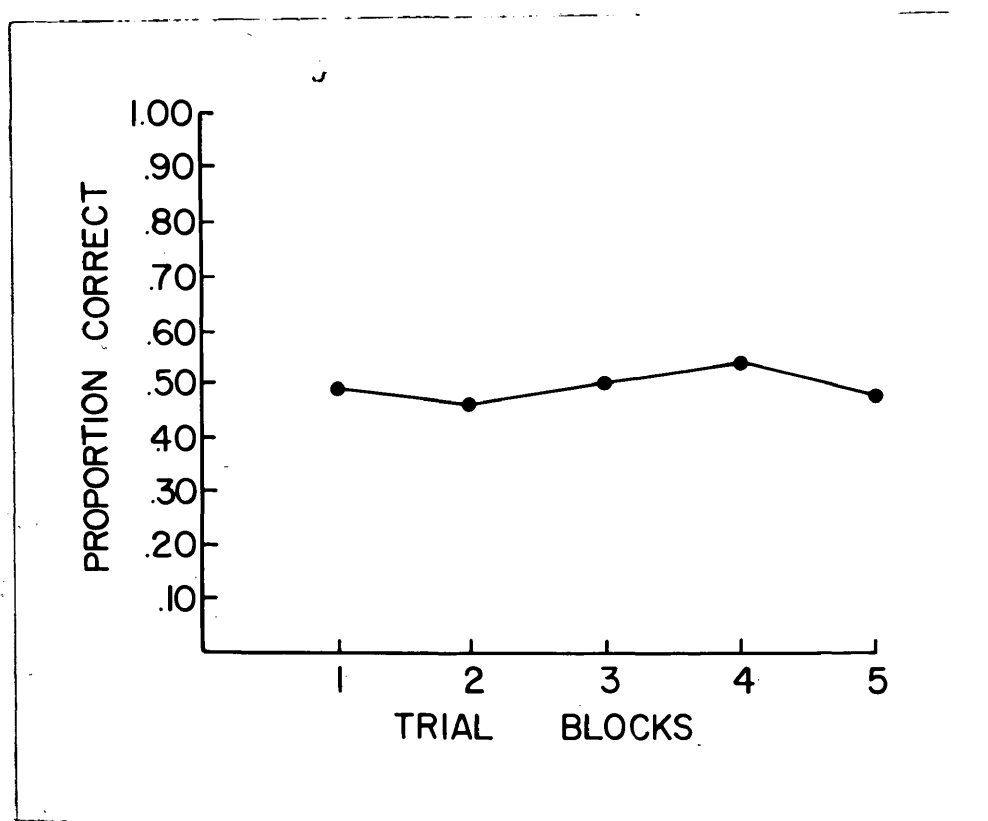


Fig. 1. Proportion of correct responses as a function of trial blocks.

All contrasts were found significant at the .01 level of confidence.

Across the five TB (numbered 1 thru 5) ss averaged proportions of .49, .47, .50, .53, and .49, respectively. The analysis resulted in an $F(4,288) = 7.68, p < .001$. All contrasts were found significant at the .01 level, except TB1 vs TB3 (.05 level) and TB1 vs TB 5 (not significant). Figure 1 depicts how performance decreased from TB1 to TB2, but then increased steadily from TB2 to TB3 and finally reached its peak at TB4; thereafter, performance decreased at TB5 to a level slightly below that of TB1. A trend analysis revealed only a positive linear function $F(4,445) = 8.73, p < .001$.

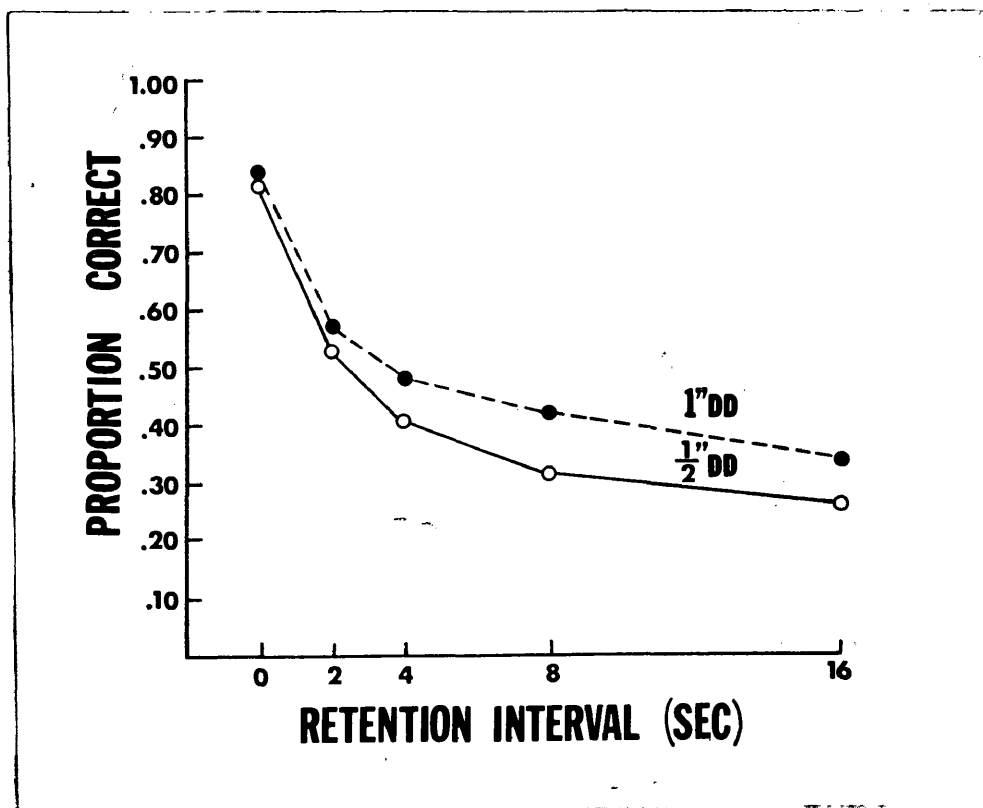


Fig. 2. Interaction of digit duration with retention interval.

Analysis of DD as a function of RI resulted in a significant interaction $F(4,288) = 3.09$, $p < .025$. Figure 2 presents graphically the differences in proportion of correct responses for each of the two levels of DD across levels of RI.

A simple main effects analysis resulted in a significant difference only at the 4 sec. RI, $F(1,244) = 37.01$, $p < .001$; the 8 sec. RI, $F(1,244) = 71.68$, $p < .001$; and the 16 sec. RI, $F(1,244) = 31.86$, $p < .001$.

Levels of IDI were found to significantly interact with RI, $F(8,288) = 3.46$, $p < .005$. Figure 3 depicts this relationship. An

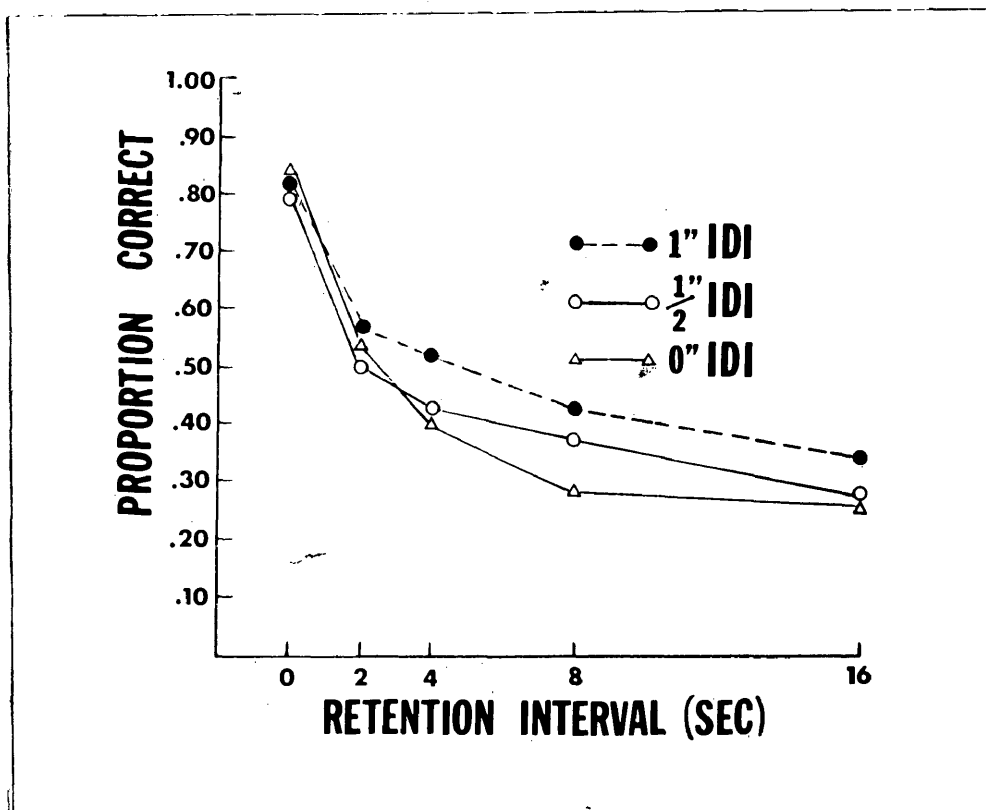


Fig. 3. Interaction of interdigit interval with retention interval.

analysis of the simple main effects resulted in significant differences found only at the 2 sec. RI, $F(2,244) = 3.68, p < .05$; the 4 sec. RI, $F(2,244) = 14.80, p < .001$; the 8 sec. RI, $F(2,244) = 17.66, p < .001$; and the 16 sec. RI, $F(2,244) = 7.09, p < .005$. All contrasts at the 2, 4, 8, and 16 sec. RIs were found significant at the .01 level.

An analysis of the levels of ET as a function of RI revealed a significant interaction $F(8,288) = 2.74, p < .01$. This relationship is graphically depicted in Figure 4. A simple main effects analysis resulted in the levels of ET being significantly different at the 0 sec.

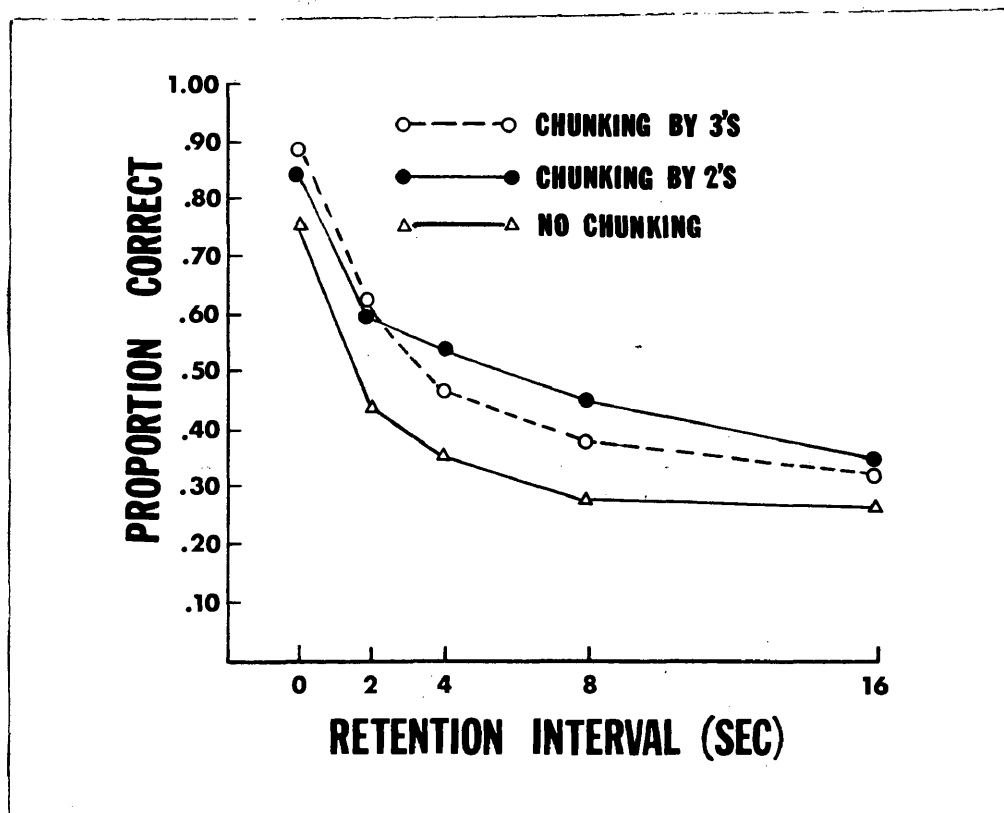


Fig. 4. Interaction of encoding techniques with retention interval.

RI, $F(2,244) = 18.09$, $p < .001$; the 2 sec. RI, $F(2,244) = 34.59$, $p < .001$; the 4 sec. RI, $F(2,244) = 35.61$, $p < .001$; the 8 sec. RI, $F(2,244) = 26.47$, $p < .001$; and at the 16 sec. RI, $F(2,244) = 8.17$, $p < .001$. All contrasts were found to be significant at the .01 level except chunking by twos vs chunking by threes at the 2 sec. RI (not significant).

Only two additional effects were significant. The levels of RI were found to significantly interact with TB, $F(16,1152) = 5.12$, $p < .001$, and a significant second order interaction was found between ET, TB, and RI, $F(32,1152) = 2.10$, $p < .005$.

Discussion

The data confirm that when either DD or IDI were increased retention was facilitated. Smith (1971) found these DD and IDI effects using four-digit auditory stimuli, and Sitterley (1968) found these same effects using strings of visual digits. Haber and Nathanson (1969) have also shown that when either DD or IDI are increased, retention is increased. The DD effect, found in these studies, does not replicate Bergström's (1907) finding that increases in stimulus duration do not facilitate recall. The DD and IDI effects cannot be explained by efficient ET, since chunking improved retention across all levels of DD and IDI and did not interact with either variable. The fact that chunking increased retention even at the .5 sec. DD indicates that the chunking process must have been completed within the .5 sec. DD. Therefore, it is felt that the extra time available, when DD or IDI was increased, was probably used for re-

hearsal.

Efficient ET, chunking by twos or threes, increased retention considerably as compared with the effects of no chunking. This finding is in agreement with Miller (1956), Murdock (1961), and Bower (1969). However, Ss chunking by twos performed better than those chunking by threes, a finding contrary to hypothesis. A possible explanation is that chunking by threes was a less familiar technique to Ss than chunking by twos. Consequently, Ss chunking by threes may have performed considerably below their asymptotic level. A solution might be to give Ss enough practice to reach asymptote prior to the start of the experiment.

The TB analysis revealed practice effects as a positive linear trend in contrast to the absence of these effects found by Smith (1971). However, the present study differs from the Smith study in that he employed four-digit stimuli and he did not employ a chunking variable. The former difference might have resulted in practice effects due to six digits requiring a greater processing effort than four digits. However, if the latter difference resulted in practice effects this would lend some support for the explanation, previously mentioned, that Ss chunking by threes may have performed considerably below asymptote.

As the length of RI was increased from 0 to 16 sec., retention decreased with negative acceleration. This retention loss was consistent with that of Peterson and Peterson (1959) and indicates that the greatest amount of decay or retention loss occurs in the first few seconds after stimulus presentation.

First order interactions between DD and RI, and IDI and RI indicate that the facilitative effect on retention of increases in DD and IDI was greater at the longer RI than at the shorter RI. This effect, also found by Smith (1971), could be the result of increased resistance to forgetting due to more time for rehearsal. At immediate recall, stimuli at the various levels of DD and IDI probably exist as very strong memory traces, because very little time has elapsed between establishment of the traces and recall. As RI is increased, the decay rate is slower for the longer DDs and IDIs due to a stronger memory trace established by more rehearsal, i.e., increased resistance to forgetting.

The effect of efficient ET seems to be that through a perceptual reorganization they allow for more items to be stored in fewer locations. This may be facilitative in two ways. First, it may decrease the amount of interference between items by decreasing the number of locations needed for storage. This suggests that the more locations needed to store stimulus items, the greater the interference. Second, because of fewer locations it might make the retrieval process more efficient. As an example, retrieval when chunking by threes requires extracting the contents of only two locations instead of six locations when not chunking. The fact that at the 0 sec. RI (immediate recall) Ss chunking by threes did better than Ss chunking by twos, who in turn did better than Ss not chunking supports both explanations.

Only a speculative explanation can be offered for the crossover of the chunking by twos and chunking by threes retention curves

(see Figure 4). Even though at immediate recall chunking by threes facilitated retention over chunking by twos, as RI was increased just the opposite occurred. Storing three digits in one location (chunking by threes) might cause greater intrachunk interference than when storing only two digits in each location (chunking by twos). If it is assumed that this intrachunk interference increases with length of RI, then chunking by threes would be increasingly less facilitative of recall as RI is increased. The effect might involve a confusion of the sequential relationships within the chunk, leading the S to confuse the sequential order of the intrachunk items. In scoring Ss' responses it was noticed that occasionally Ss would report the correct digits but not in their correct serial position (e.g., 486 instead of 864 the correct order). This superficial observation would seem to indicate a loss of the sequential relationships within the chunk. Moreover, if one chunk was incorrectly recalled when chunking by threes it would increase the S's error score by three points whereas it would only increase by two points if the S were chunking by twos. As an example, if both groups of chunking Ss were to lose one chunk over a 16 sec. RI it is obvious that chunking by twos would show the better performance.

The present experiment has provided at least some concrete indication that errors in short-term retention may be due not only to forgetting caused by insufficient rehearsal, for example, but also to inefficiencies in the encoding process. These two sources of error are independently manipulable through variations in encoding instructions and stimulus presentation rate.

Some considerations for future experimentation are suggested by the present study. First, a study should be conducted to explore in a more parametric fashion the effects on recall of different lengths of auditory strings. This would indicate the effect of different levels of item interference (number or items/stimulus) across RI. Second, an experiment should be conducted to determine the effects, across RI, of DD at the minimum level required for intelligibility. This would reveal the nature of the decay function when organizational techniques and rehearsal could not be employed. Third, by employing an ET and incrementally increasing DD, starting at the minimum duration needed for intelligibility, the minimum amount of time needed to employ an ET could be identified. Perhaps the intelligibility duration should be the basis for the parametric increases in DD. It is felt that a DD X ET interaction would be found when comparing the effects of a DD as long as one second with those of a DD presented at the intelligibility duration. This same procedure of incrementally increasing DD starting at the intelligibility duration could be used to determine the minimum amount of time that DD must be increased in order to significantly facilitate retention when an ET is not used. It is quite possible that the DD level found from this procedure would be the minimum time necessary for rehearsal. Fourth, a study should be conducted to determine the effects of different size chunks (2, 3, 4, and 5 items/chunk) across RI. This would provide a better understanding of intrachunk interference as it relates to retention across RI.

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Appendix

Instructions

General

This experiment is designed to investigate short-term memory. It is not a test that you should become apprehensive about in any way. All you will have to do is remember six-digit numbers over short intervals of time. You will hear on the tape recorder the number which you are to remember until the E asks for its recall. One purpose of this experiment is to investigate the effects of different grouping techniques on STM. (See below for continuation to chunkers and non-chunkers.)

SS not chunking

You are assigned to a no grouping condition and must therefore remember each digit separately. If you experience a tendency to group the digits in any way, you must persist and avoid using such a technique. It is very important that you try to remember each digit separately within the number. You must not group the digits in any way. As an example, you would remember the number 142873 as 1-4-2-8-7-3 and not 14-28-73 or 142-873 or any other combination or grouping. Failure to follow these instructions would be cheating and you would defeat the purpose of the experiment; therefore, your complete cooperation is requested to ensure its success. Immediately after hearing the number you are to read the letters that you see before you, out loud, as rapidly as you can. You are to start with a different row of letters each time. Do not start with the same row twice in succession. Continue reading the letters until E says, "Recall"; then try to remember the digits of the number just as you heard them on the tape recorder and repeat them out loud to the E. After this you will hear another six-digit number and the procedure will be repeated. Do you understand what you are to do? Let's try a few practice trials.

SS chunking

You are assigned to a grouping condition and must therefore group the digits of the number by twos (threes). If you experience a tendency to group the digits in any other way or to remember them separately, you must resist and avoid using these other techniques. It is very important that you try to remember the number by grouping the digits by twos (threes). As an example, if you heard the number 142873, you would remember it as fourteen, twenty-eight, seventy-three, (one hundred-forty-two, eight hundred-seventy-three) or one-four, two-eight, seven-three, (one-four-two, eight-seven-three) either way as long as you group the digits by twos (threes). Failure to follow these instructions would be cheating and you would defeat the purpose of the experiment; therefore, your complete cooperation is requested to ensure its success. Immediately after hearing the number you are to read the

letters that you see before you, out loud, as rapidly as you can. You are to start with a different row of letters each time. Do not start with the same row twice in succession. Continue reading the letters until the E says, "Recall"; then try to remember the number as you had grouped it by twos (threes) and repeat it out loud to the E. After this you will hear another six-digit number and the procedure will be repeated. Do you understand what you are to do? Let's try a few practice trials.